Distribution valuability of report Approved for public release; distribution unlimited.  4. Performing organization report number(s) AFOSR - F49620 - 92 - J - 0400  5. MONITORING ORGANIZATION REPORT Number(s) AFOSR-TF-94 0335  6. NAME OF PERFORMING ORGANIZATION California Institute of Technology 6. ADDRESS (City, State, and ZIP Code) Department of Electrical Engineering MS 116-81 Pasadena CA 91125  8. NAME OF FUNDING/SPONSORING ORGANIZATION AFOSR  PAGE OF FUNDING/SPONSORING ORGANIZATION AFOSR  PAGE OF FUNDING NUMBER  PAGE OF FUNDING NUMBER  PAGE OF FUNDING NUMBER  PROGRAM ELEMENT NO. BORLAN AFB DC 20332-0001  10. SOURCE OF FUNDING NUMBERS  PROGRAM ELEMENT NO. BORLAN AFB DC 20332-0001  11. TITLE (Include Security Classification) 3-D Optical Memory Disk  12. PERSONAL AUTHOR(s) Demetri Psaltis  13b. TYPE OF REPORT Technical FROM 7/1/93 TO 2/28/94  14. DATE OF REPORT (Year, Month, Day) 15. PAGE COUNT Technical FROM 7/1/93 TO 2/28/94  16. SUPPLEMENTARY NOTATION	CEPTIBLE CA			. ~		`		
DISTRIBUTION/AVAILABILITY OF REPORT Approved for pith 1st release; distribution unlimited.  4. PERIORAMNG ORGANIZATION REPORT NUMBER(S) AFOSR - 749620 - 92 - J - 0400 AFOSR-R- 94 0 3 3 5  5. MONITORING ORGANIZATION REPORT NUMBER(S) AFOSR-R- 94 0 3 3 5  6. NAME OF PERFORMING ORGANIZATION CRAILfornia Institute of fire population Technology 6. ADDRESS (Gry, State, and ZIP Code) Department of Electrical Engineering HS 116-81 Fasadena CA 91125 COMMINATOR ORGANIZATION Technology 6. ADDRESS (Gry, State, and ZIP Code) Department of Electrical Engineering HS 116-81 FASAGEN (FUNDING/SPONSORING ON ADDRESS (Gry, State, and ZIP Code) Department of Electrical Engineering HS 116-81 FASAGEN (FUNDING/SPONSORING ON ADDRESS (Gry, State, and ZIP Code)  10. FORCE OF FUNDING NUMBERS FUNDING/SPONSORING FOR ADDRESS (Gry, State, and ZIP Code)  11. TITLE (Includes Security Classification) 3-D Optical Memory Disk 11. TITLE (Includes Security Classification) 3-D Optical Memory Disk 11. TITLE (Includes Security Classification) 12. TYPE OF REPORT Technical FROM / 1/93 to 2/28/94 12. PERSONAL AUTHOR(S) Demetri Psaltis 13. TYPE OF REPORT Technical FROM / 1/93 to 2/28/94 14. DATE OF REPORT (Year, Month, Day) 15. PAGE COUNT 16. SUPPLEMENTARY NOTATION  17. COSAT (CODES FIELD GROUP SUB-GROUP  18. SUB-ECT TERMS (Continue on reverse if necessary and identify by block number) 19. ABSTRACT (Continue on reverse if necessary and identify by block number) 19. ABSTRACT (Continue on reverse if necessary and identify by block number) 19. ABSTRACT (Continue on reverse if necessary and identify by block number) 19. ABSTRACT (Continue on reverse if necessary and identify by block number) 19. ABSTRACT (Continue on reverse if necessary and identify by block number) 19. ABSTRACT (Continue on reverse if necessary and identify by block number) 19. ABSTRACT (Continue on reverse if necessary and identify by block number) 19. ABSTRACT (Continue and reverse if necessary and identify by block number) 19. ABSTRACT (Continue on reverse if necessary and identify by block	SECURITICA	SIFICATION OF	HIS PAGE	THE MILLION	PAGE	<del></del>		
The December of December of Performing Organization Report number(s)  A POSE F 49620 - 92 - 3 - 0400  See MAME OF PERFORMING ORGANIZATION Set Office SYMBOL (if applicable)  Technology  See ADDRESS (City, State, and ZIP Code)  Department of Electrical Engineering  MS 116-81  Pasadens CA 91125  Be NAME OF FUNDING SPONSORING  ORGANIZATION  A DORESS (City, State, and ZIP Code)  Department of Electrical Engineering  MS 116-81  Pasadens CA 91125  Be NAME OF FUNDING SPONSORING  ORGANIZATION  A DORESS (City, State, and ZIP Code)  Department of Electrical Engineering  MS 116-81  Pasadens CA 91125  Be NAME OF FUNDING SPONSORING  ORGANIZATION  A DORESS (City, State, and ZIP Code)  Department of Electrical Engineering  MS 116-81  Be ADDRESS (City, State, and ZIP Code)  Department of Electrical Engineering  MS 116-81  Be ADDRESS (City, State, and ZIP Code)  Department of Electrical Engineering  MS 116-81  Be ADDRESS (City, State, and ZIP Code)  Department of Electrical Engineering  MS 116-81  Be ADDRESS (City, State, and ZIP Code)  Department of Electrical Engineering  MS 116-81  Department of Electrical Engineering  MS 116-81  Be ADDRESS (City, State, and ZIP Code)  Department of Electrical Engineering  MS 116-81  Depart	T A			2 ECTE	. RESTRICTIVE A	MARKINGS		•
A PENGRAMING ORGANIZATION REPORT NUMBERS)  AFOSR - F49620 - 92 - J - 0400  S. MANE OF PERGRAMING GRGANIZATION  (California Institute of Pengraming Gradanization (Papplicable))  Example of Pengraming Gradanization  (Fapplicable)  Example of Pengraming Gradanization  (Fapplicable)  F. ADDRESS (Ciry, State, and 2IP Code)  Department of Electrical Engineering  INS 116-81  Pasadens CA 91125  Ban Mark CF PUNDING/SPONSORING  ORGANIZATION  (Fapplicable)  F. ADDRESS (Ciry, State, and 2IP Code)  Department of Electrical Engineering  INS 116-81  Ban Mark CF PUNDING/SPONSORING  ORGANIZATION  PROCEEDING OF PROCEEDING ORGANIZATION  (Fapplicable)  F. ADDRESS (Ciry, State, and 2IP Code)  PROCEEDING OF PUNDING STRUMENT IDENTIFICATION NUMBER  F. 490 2 9 2 - 0 9 0 0  F. ADDRESS (Ciry, State, and 2IP Code)  IN SUDIECT OF FUNDING NUMBERS  FOORCE OF FUNDING NUMBERS  PROJECT  INS UNDICE OF FUNDING NUMBERS  PROJECT  NO.  10 SOURCE OF FUNDING NUMBERS  FROM 7 1/93 TO 2/28/94  14. DATE OF REPORT (Year, Month, Day)  15. PAGE COUNT  Technical  FROM 7 1/93 TO 2/28/94  16. SUPPLEMENTARY NOTATION  17. COSATI CODES  FIELD GROUP  SUB-GROUP  18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)  19. ABSTRACT (Continue on reverse if necessary and identify by block number)  19. ABSTRACT (Continue on reverse if necessary and identify by block number)  19. ABSTRACT (Continue on reverse if necessary and identify by block number)  19. ABSTRACT (Continue on reverse if necessary and identify by block number)  19. ABSTRACT (Continue on reverse if necessary and identify by block number)  19. ABSTRACT (Continue on reverse if necessary and identify by block number)  19. ABSTRACT (Continue on reverse if necessary and identify by block number)  19. ABSTRACT (Continue on reverse if necessary and identify by block number)  19. ABSTRACT (Continue on reverse if necessary and identify by block number)  19. ABSTRACT (Continue on reverse if necessary and identify by block number)  19. ABSTRACT (Continue on reverse if necessary and identif	Zi Zb. DECLASSIF		ann aens seul saidt bill 1961	B	Approv	ed for public	roleas	6 <b>0 \$</b>
AFOSR - F49620 - 92 - J - 0400  6. NAME OF PRECENTING ORGANIZATION (If applicable)  7. NAME OF PRECENTING ORGANIZATION (If applicable)  7. NAME OF MONITORING ORGANIZATION  8. NAME OF FUNDING STOKESORING  9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER  8. NAME OF FUNDING STOKESORING  9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER  8. NAME OF FUNDING NUMBERS  9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER  8. NAME OF FUNDING NUMBERS  9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER  8. NAME OF FUNDING NUMBERS  9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER  8. NAME OF FUNDING NUMBERS  9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER  8. NAME OF FUNDING NUMBERS  9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER  8. NAME OF FUNDING NUMBERS  8. NAME OF FUNDING STOKESORING  10. SOURCE OF FUNDING NUMBERS  8. NAME OF FUNDING STOKESORING  11. TITLE (Include Security Classification)  12. PROCUREMENT INSTRUMENT INSTRUMENT IDENTIFICATION NUMBER  8. NAME OF FUNDING NUMBERS  8. NAME OF FUNDING NUM			0	1				
Technology  6. ADDRESS (Cry, State, and ZIP Code) Department of Electrical Engineering NS 116-81 Pasadena CA 91125  8. NAME OF FUNDING (SPONSORING ORGANIZATION PLANE) DEPARTMENT (I SPONSORING ORGANIZATION PLANE)  13. INTER OF REPORT								
SC. ADDRESS (City, State, and 2IP Code)  Department of Electrical Engineering  NS 116-81  Pasadena CA 91125  B. NAME OF FUNDING/SPONSORING ORGANIZATION  AF OSR  C. ADDRESS (City, State, and ZIP Code)  DEPARTMENT (Include Security Classification)  10. SOURCE OF FUNDING SPONSORING ORGANIZATION  FOUR CITY (Include Security Classification)  11. TITLE (Include Security Classification)  3.D Optical Memory Disk  12. PERSONAL AUTHOR(5) Demetri Psaltis  13a. TYPE OF REPORT Psaltis  13a. TYPE OF REPORT Psaltis  13b. TIME COVERED  FELD GROUP  10. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)  17. COSATI CODES  FIELD GROUP SUB-GROUP  18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)  Recently, a new method of multiplexing holograms by rotating the material, or equivalently, the recording beams was invented. This method is called Peristropic (Greek for rotation) multiplexing and is briefly described. Peristropic multiplexing and be toring using by postating using DuPont's HIRE-150 photopolymer film. A total of 295 holograms were multiplexed in the 38 kgm thick photopolymer disk by combining peristropic multiplexing with angle multiplexing. In addition, it is shown that combining both angle and peristrophic multiplexing the storage density of 3.D disks is greatly enhanced.  20. DISTRIBUTION/AVAILABILITY OF ABSTRACT  OUNCLASSIFICD/MULMITED ABAME AS RPT. OTIC USERS  21. ABSTRACT SECURITY CLASSIFIC  Paratical Area Code)  22. NAME OF RESPONSIBLE INDIVIDUAL  Benefit Paaltie  22. NAME OF RESPONSIBLE INDIVIDUAL  23. NAME OF RESPONSIBLE INDIVIDUAL  24. ABSTRACT SECURITY CLASSIFIC  Dematri Paaltie  25. Paratical Area Code)  26. OFFICE SYMBOL  27. ABSTRACT SECURITY CLASSIFIC  Dematri Paaltie  28. TELEPHONE (Include Area Code)  29. OFFICE SYMBOL  20. DISTRIBUTION/AVAILABILITY OF ABSTRACT  Dematri Paaltie  20. OFFICE SYMBOL  21. ABSTRACT SECURITY CLASSIFIC  Dematri Paaltie  22. NAME OF RESPONSIBLE INDIVIDUAL			ORGANIZATION Ute of		78. NAME OF MONITORING ORGANIZATION			
Be. AMRE OF FUNDING/SPONSORING ORGANIZATION  AF OS R  Be. ADDRESS (Cry. State, and ZIP Code)  10. SOURCE OF FUNDING NUMBERS  PROJECT TASK WORK UNIT ACCESSION NO. 6/102 F PROJECT TASK WORK UNIT ACCESSION NO. 6/102 F PROJECT TOO. 72 3 0 5 DS  11. TITLE (include Security Classification)  3-D Optical Memory Disk  12. PERSONAL AUTHOR(S)  Demetri Psaltis  13a. TYPE OF REPORT Psaltis  13b. TIME COVERED FROM 7 / 1/93 TO 2/28/94  14. DATE OF REPORT (Year, Month, Day)  15. PAGE COUNT Technical  17. COSATI CODES FIELD GROUP  18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)  19. ABSTRACT (Continue on reverse if necessary and identify by block number)  Recently, a new method of multiplexing holograms by rotating the material, or equivalently, the recording beams was invented. This method is called Peristropic (Greek for rotation) multiplexing and is briefly described. Peristropic multiplexing can be combined with other multiplexing methods to increase the storage density of holographic storage systems such as the previously reported 3-D disk. Peristropic multiplexing was experimentally demonstrating using Dupon's HRP-150 photopolymer film. A total of 295 holograms were multiplexed in the 38µm thick photopolymer disk by combining peristropic multiplexing with angle multiplexing. In addition, it is shown that combining both angle and peristrophic multiplexing the storage density of 3-D disks is greatly enhanced.  20. DISTRIBUTION/AVAILABILITY OF ABSTRACT  DUNCLASSIFICDURUMENTED   3 AME OF REPORTS (Include Area Code)  21. ABSTRACT SECURITY CLASSIFICATION (Include Area Code)  222. NAME OF REPORTS (Include Area Code)  222. NAME OF REPORTS (Include Area Code)  222. OFFICE SYMBOL  223. NAME OF REPORTS (Include Area Code)  224. TELEPHONE (Include Area Code)  225. TELEPHONE (Include Area Code)  226. OFFICE SYMBOL	6c ADDRESS (	City, State, and ent of Ele		neering	7b. ADDRESS (City, State, and ZIP Code)			
BC ADDRESS (Cry. State, and ZIP Code)  BC ADDRESS (Cry. State, and ZIP Code, and ZIP Code, and Code)  BC ADDRESS (Cry. State, and ZIP Code, and Code, and Code)  BC ADDRESS (C				8b. OFFICE SYMBOL	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER			
BC ADDRESS (Cry. State, and ZIP Code)    Color   Code   Co					F49620 92-J-040D			
Bolling ARB DC 20332-000 61102 F 2305 DS ACCESSION NO. 61102 F 230			ZIP Code)	1_/				
11. TITLE (Include Security Classification) 3-D Optical Memory Disk  12. PERSONAL AUTHOR(S) Demetri Psaltis 13a. TYPE OF REPORT Technical FROM 7 / 1/93 To 2/28/94 14. DATE OF REPORT (Year, Month, Day) 15. PAGE COUNT 16. SUPPLEMENTARY NOTATION  17. COSATI CODES FIELD GROUP SUB-GROUP  19. ABSTRACT (Continue on reverse if necessary and identify by block number)  19. Recently, a new method of multiplexing holograms by rotating the material, or equivalently, the recording beams was invented. This method is called Peristropic (Greek for rotation) multiplexing and is briefly described. Peristropic multiplexing can be combined with other multiplexing methods to increase the storage density of holographic storage systems such as the previously reported 3-D disk. Peristropic multiplexing was experimentally demonstrating using DuPont's HRF-150 photopolymer film. A total of 295 holograms were multiplexed in the 38 mm thick photopolymer disk by combining peristropic multiplexing with angle multiplexing. In addition, it is shown that combining both angle and peristrophic multiplexing the storage density of 3-D disks is greatly enhanced.  20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNICLASSIFICUMLIMITED AME AS RPT. DITIC USERS 21. ABSTRACT SECURITY CLASSIFIC UNICLASSIFICUMLIMITED AME AS RPT. DITIC USERS 22. NAME OF RESPONSIBLE INDIVIDUAL Demetri Psaltis	B	20.	160 00	7022200	ELEMENT NO.	NO.	NO.	ACCESSION NO.
132. TYPE OF REPORT Technical 133. TIME COVERED FROM 7 / 1/93 TO 2/28/94 14. DATE OF REPORT (Year, Month, Day) 15. PAGE COUNT Technical 16. SUPPLEMENTARY NOTATION 17. COSATI CODES 18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) 19. ABSTRACT (Continue on reverse if necessary and identify by block number) 19. ABSTRACT (Continue on reverse if necessary and identify by block number) Recently, a new method of multiplexing holograms by rotating the material, or equivalently, the recording beams was invented. This method is called Peristropic (Greek for rotation) multiplexing and is briefly described. Peristropic multiplexing can be combined with other multiplexing methods to increase the storage density of holographic storage systems such as the previously reported 3-D disk. Peristropic multiplexing was experimentally demonstrating using DuPont's HRF-150 photopolymer film. A total of 295 holograms were multiplexed in the 38µm thick photopolymer disk by combining peristropic multiplexing with angle multiplexing. In addition, it is shown that combining both angle and peristrophic multiplexing the storage density of 3-D disks is greatly enhanced.  20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNICLASSIFIED/UNILIMITED  AMAE OF RESPONSIBLE INDIVIDUAL Demetri Paaltis	11. TITLE (Include Security Classification)							
Demetri Psaltis  13a. TIME COVERED Technical 13b. TIME COVERED FROM 7 / 1/93 TO 2/28/94 14. DATE OF REPORT (Year, Month, Day) 15. PAGE COUNT Technical FROM 7 / 1/93 TO 2/28/94 14. DATE OF REPORT (Year, Month, Day) 15. PAGE COUNT 11.  16. SUPPLEMENTARY NOTATION  17. COSATI CODES 18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)  19. ABSTRACT (Continue on reverse if necessary and identify by block number)  Recently, a new method of multiplexing holograms by rotating the material, or equivalently, the recording beams was invented. This method is called Peristropic (Greek for rotation) multiplexing and is briefly described. Peristropic multiplexing can be combined with other multiplexing methods to increase the storage density of holographic storage systems such as the previously reported 3-D disk. Peristropic multiplexing was experimentally demonstrating using DuPont's HRR-150 photopolymer film. A total of 295 holograms were multiplexed in the 38µm thick photopolymer disk by combining peristropic multiplexing with angle multiplexing. In addition, it is shown that combining both angle and peristrophic multiplexing the storage density of 3-D disks is greatly enhanced.  20. DISTRIBUTION/AVAILABILITY OF ABSTRACT DICCUSERS 21. ABSTRACT SECURITY CLASSIFIC DUNCLASSIFICD/UNLIMITED SAME AS RPT. DICCUSERS 222. NAME OF RESPONSIBLE INDIVIDUAL BIS 395-4856								
13b. TIME COVERED FROM 7 / 1/93 TO 2/28/94 14. DATE OF REPORT (Year, Month, Day) 15. PAGE COUNT Technical FROM 7 / 1/93 TO 2/28/94 14. DATE OF REPORT (Year, Month, Day) 15. PAGE COUNT 11.  16. SUPPLEMENTARY NOTATION  17. COSATI CODES 18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)  19. ABSTRACT (Continue on reverse if necessary and identify by block number)  Recently, a new method of multiplexing holograms by rotating the material, or equivalently, the recording beams was invented. This method is called Peristropic (Greek for rotation) multiplexing and is briefly described. Peristropic multiplexing can be combined with other multiplexing methods to increase the storage density of holographic storage systems such as the previously reported 3-D disk. Peristropic multiplexing was experimentally demonstrating using DuPont's HRF-150 photopolymer film. A total of 295 holograms were multiplexed in the 38 multick photopolymer disk by combining peristropic multiplexing with angle multiplexing. In addition, it is shown that combining both angle and peristrophic multiplexing the storage density of 3-D disks is greatly enhanced.  20. DISTRIBUTION/AVAILABILITY OF ABSTRACT DIC USERS 21. ABSTRACT SECURITY CLASSIFIC Number 222. NAME OF RESPONSIBLE INDIVIDUAL 818 395-4856	12. PERSONAL AUTHOR(S)							
17. COSATI CODES  18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)  19. ABSTRACT (Continue on reverse if necessary and identify by block number)  Recently, a new method of multiplexing holograms by rotating the material, or equivalently, the recording beams was invented. This method is called Peristropic (Greek for rotation) multiplexing and is briefly described. Peristropic multiplexing can be combined with other multiplexing was experimentally demonstrating using DuPont's HRF-150 photopolymer film. A total of 295 holograms were multiplexed in the 38µm thick photopolymer disk by combining peristropic multiplexing with angle multiplexing. In addition, it is shown that combining both angle and peristrophic multiplexing the storage density of 3-D disks is greatly enhanced.  20. DISTRIBUTION/AVAILABILITY OF ABSTRACT  UNCLASSIFIED/UNLIMITED SAME AS RPT. DTIC USERS  21. ABSTRACT SECURITY CLASSIFIC  12. ABSTRACT SECURITY CLASSIFIC  22. NAME OF RESPONSIBLE INDIVIDUAL  22. STELEPHONE (include Area Code)	13a. TYPE OF	REPORT	13b. TIME C	OVERED 1/93 TO 2/28/94	4/22/94	RT (Year, Month,	Day) 15	
Recently, a new method of multiplexing holograms by rotating the material, or equivalently, the recording beams was invented. This method is called Peristropic (Greek for rotation) multiplexing and is briefly described. Peristropic multiplexing can be combined with other multiplexing methods to increase the storage density of holographic storage systems such as the previously reported 3-D disk. Peristropic multiplexing was experimentally demonstrating using DuPont's HRF-150 photopolymer film. A total of 295 holograms were multiplexed in the 38µm thick photopolymer disk by combining peristropic multiplexing with angle multiplexing. In addition, it is shown that combining both angle and peristrophic multiplexing the storage density of 3-D disks is greatly enhanced.  20. DISTRIBUTION/AVAILABILITY OF ABSTRACT  UNCLASSIFIED/UNCIMITED SAME AS RPT. DITIC USERS  21. ABSTRACT SECURITY CLASSIFIC  N  22b. TELEPHONE (Include Area Code) 22c. OFFICE SYMBOL  818 395~4856	16. SUPPLEME	NTARY NOTAT						
Recently, a new method of multiplexing holograms by rotating the material, or equivalently, the recording beams was invented. This method is called Peristropic (Greek for rotation) multiplexing and is briefly described. Peristropic multiplexing can be combined with other multiplexing methods to increase the storage density of holographic storage systems such as the previously reported 3-D disk. Peristropic multiplexing was experimentally demonstrating using DuPont's HRF-150 photopolymer film. A total of 295 holograms were multiplexed in the 38µm thick photopolymer disk by combining peristropic multiplexing with angle multiplexing. In addition, it is shown that combining both angle and peristrophic multiplexing the storage density of 3-D disks is greatly enhanced.  20. DISTRIBUTION/AVAILABILITY OF ABSTRACT  UNCLASSIFIED/UNCIMITED SAME AS RPT. DITIC USERS  21. ABSTRACT SECURITY CLASSIFIC  N  22b. TELEPHONE (Include Area Code) 22c. OFFICE SYMBOL  818 395~4856	17.	COSATI	CODES	18. SUBJECT TERMS (C	ontinue on reverse	e if necessary and	d identify	by block number)
Recently, a new method of multiplexing holograms by rotating the material, or equivalently, the recording beams was invented. This method is called Peristropic (Greek for rotation) multiplexing and is briefly described. Peristropic multiplexing can be combined with other multiplexing methods to increase the storage density of holographic storage systems such as the previously reported 3-D disk. Peristropic multiplexing was experimentally demonstrating using DuPont's HRF-150 photopolymer film. A total of 295 holograms were multiplexed in the 38µm thick photopolymer disk by combining peristropic multiplexing with angle multiplexing. In addition, it is shown that combining both angle and peristrophic multiplexing the storage density of 3-D disks is greatly enhanced.  20. DISTRIBUTION/AVAILABILITY OF ABSTRACT  UNCLASSIFIED/UNLIMITED  SAME AS RPT.  DTIC USERS  21. ABSTRACT SECURITY CLASSIFIC  UNCLASSIFIED/UNLIMITED  SAME AS RPT.  DTIC USERS  22b. TELEPHONE (Include Area Code)  22c. OFFICE SYMBOL and STRACT  Bill 395-4856				1				
Recently, a new method of multiplexing holograms by rotating the material, or equivalently, the recording beams was invented. This method is called Peristropic (Greek for rotation) multiplexing and is briefly described. Peristropic multiplexing can be combined with other multiplexing methods to increase the storage density of holographic storage systems such as the previously reported 3-D disk. Peristropic multiplexing was experimentally demonstrating using DuPont's HRF-150 photopolymer film. A total of 295 holograms were multiplexed in the 38µm thick photopolymer disk by combining peristropic multiplexing with angle multiplexing. In addition, it is shown that combining both angle and peristrophic multiplexing the storage density of 3-D disks is greatly enhanced.  20. DISTRIBUTION/AVAILABILITY OF ABSTRACT  UNCLASSIFIED/UNLIMITED  SAME AS RPT.  DTIC USERS  21. ABSTRACT SECURITY CLASSIFIC  UNCLASSIFIED/UNLIMITED  SAME AS RPT.  DTIC USERS  22b. TELEPHONE (Include Area Code)  22c. OFFICE SYMBOL and STRACT  Bill 395-4856				4				
Peristropic multiplexing was experimentally demonstrating using DuPont's HRF-150 photopolymer film. A total of 295 holograms were multiplexed in the 38µm thick photopolymer disk by combining peristropic multiplexing with angle multiplexing. In addition, it is shown that combining both angle and peristrophic multiplexing the storage density of 3-D disks is greatly enhanced.  20. DISTRIBUTION/AVAILABILITY OF ABSTRACT  UNCLASSIFIED/UNILIMITED  SAME AS RPT.  DTIC USERS  21. ABSTRACT SECURITY CLASSIFIC.  12. ABSTRACT SECURITY CLASSIFIC.  22. NAME OF RESPONSIBLE INDIVIDUAL  Demetri Psaltis  22. OFFICE SYMBOL  818 395-4856	Recently, a method is	new method	of multiplexing ho pic (Greek for rota	lograms by rotating the r	material, or equiva	Peristropic mu	iltinlexina	can be combined with
UNCLASSIFIED/UNLIMITED SAME AS RPT. DTIC USERS  22a. NAME OF RESPONSIBLE INDIVIDUAL Demetri Psaltis  22b. TELEPHONE (include Area Code) 818 395-4856	Peristropic were multi	multiplexing  plexed in the	was experimentall 38µm thick photor	storage density of hology by demonstrating using I polymer disk by combining	graphic storage sy DuPont's HRF-15( ing peristropic mu	stems such as the photopolymer with a	ne previou film. A t	isly reported 3-D disk.  otal of 295 holograms  tipleving. In addition
UNCLASSIFIED/UNLIMITED SAME AS RPT. DTIC USERS  22a. NAME OF RESPONSIBLE INDIVIDUAL Demetri Psaltis  22b. TELEPHONE (include Area Code) 818 395-4856							111101	
22a. NAME OF RESPONSIBLE INDIVIDUAL Demetri Psaltis  22b. TELEPHONE (include Area Code) 818 395~4856	·				21. ABSTRACT SE	CURITY CLASSIFIC	11	
DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE	22a. NAME C	F RESPONSIBLE	INDIVIDUAL		225. TELEPHONE ( 818 395-485	include Area Code	e) 22c. O	FICE SYMBOL .
				Previous editions are	obsolete.	SECURITY	CLASSIFIC	ATION OF THIS PAGE

94 6 6 045

Approved for public release; distribution unlimited.

Grant AFOSR - F49620-92-J-0400

Technical Report

Report Period: July 1, 1993 to February 28, 1994

3-D OPTICAL MEMORY DISK

Demetri Psaltis

Submitted to:

Dr. Alan E. Craig

Air Force Office of Scientific Research

Bolling Air Force Base, Washington, D. C.

Principal Investigator:

DTIC QUALITY INSPECTED 8

Dr. Demetri Psaltis

California Institute of Technology

Department of Electrical Engineering

Pasadena, California 91125

#### Abstract

Recently, a new method of multiplexing holograms by rotating the material, or equivalently, the recording beams was invented. This method is called Peristrophic (Greek for rotation) multiplexing and is briefly described. Peristrophic multiplexing can be combined with other multiplexing methods to increase the storage density of holographic storage systems such as the previously reported 3-D disk. Peristrophic multiplexing was experimentally demonstrated using DuPont's HRF-150 photopolymer film. A total of 295 holograms were multiplexed in a 38µm thick photopolymer disk by combining peristrophic multiplexing with angle multiplexing. In addition, it is shown that combining both angle and peristrophic multiplexing the storage density of 3-D disks is greatly enhanced.

Acces	sion For	· 14
MTIS	GRAMI	
DTIC	╗	
Unann		
<b>Ja</b> sti	fication_	
By Distr	ibution/-	<u> </u>
	lability	
	Avail and	/or
Dist	Special	•
A-1		Lee and

### 1.0 Introduction

The number of holograms that can be multiplexed at a certain location on a holographic disk is primarily a function of two parameters – the system's bandwidth (either temporal or spatial frequency) and the material's dynamic range. Recently, thin film materials have been developed with relatively large dynamic range. An example of such a material is DuPont's HRF-150 photopolymer [1]. Previously we have reported 10 angle multiplexed holograms in a  $38\mu$ m thick film [2] with diffraction efficiency of  $10^{-3}$ . Since we can typically work with holographic diffraction efficiencies on the order of  $10^{-6}$ , we have sufficient dynamic range to record significantly more than 10 holograms. The angular bandwidth limitation can be alleviated by making the film thicker [3] but scattering increases rapidly with thickness in these materials. Another method that has been previously used to increase the utilization of the available bandwidth of the system is fractal sampling grids [4,5].

In this report we describe the application of peristrophic (Greek for rotation) multiplexing to holographic 3-D disks. With this method the hologram is physically rotated with the axis of rotation being perpendicular to the film's surface every time a new hologram is stored. The rotation does two things. It shifts the reconstructed image away from the detector allowing a new hologram to be stored and viewed without interference, and it can also cause the stored hologram to become non-Bragg matched. This rotation is in addition to and separate from the conventional disk rotation. In addition, peristrophic multiplexing can be combined with other multiplexing techniques such as angle or wavelength multiplexing to increase the storage density and with spatial multiplexing to increase the storage capacity of the disk.

# 2.0 Theory for Peristrophic Multiplexing

The setup for peristrophic multiplexing Fourier plane holograms is shown in

Figure 1. The reference plane wave (R) is incident at an angle  $\theta_r$  and the signal beam (S) is incident at an angle  $\theta_s$ , both angles measured with respect to the film's normal. Taking the center pixel of the image as the signal and neglecting any effects due to hologram thickness, the hologram transmittance can be written as

$$R^*S = e^{-i2\pi \frac{\sin \theta_T}{\lambda}x} e^{-i2\pi \frac{\sin \theta_T}{\lambda}x} \tag{1}$$

The hologram is then rotated by  $d\theta$  about the center of the x-y plane as shown in Figure 1. Assuming the rotation is small, this results in the coordinates being transformed according to:  $x' \approx x - y d\theta$ , and  $y' \approx y + x d\theta$ . Substituting these relations into Eq. 1, the hologram be expressed in terms of the unrotated coordinates (x,y)

$$R^{-}S = e^{-i\frac{2\pi\sin\theta_{r}x}{\lambda}}e^{-i\frac{2\pi\sin\theta_{r}x}{\lambda}}e^{-i\frac{2\pi(\sin\theta_{r}+\sin\theta_{r})d\theta_{y}}{\lambda}}.$$
 (2)

After multiplying by R and Fourier transforming, the last term in Eq. 2 results a shift in the image. The rotation required to translate the image out of the detector aperture is approximately given by,

$$d\theta \ge \frac{\frac{d}{F}}{\sin \theta_* + \sin \theta_*}.$$
 (3)

where d is the size of the image at the detector plane and F is the focal length of the lens used. For image plane holograms, the expression is [6]

$$d\theta \ge \frac{\frac{2\lambda}{\delta}}{\sin\theta_s + \sin\theta_r},\tag{4}$$

where  $1/\delta$  is the highest spatial frequency in the image. For image plane holograms, the undesired holograms are filtered out at the Fourier plane of the system. Notice that this method can be combined with other volumetric multiplexing methods to further increase the storage density.

The Bragg selectivity, assuming the reference is given by  $R = e^{-i(\frac{2\pi \sin\theta_x}{\lambda}x + \frac{2\pi \cos\theta_x}{\lambda}z)}$  and the signal given by  $S = e^{i(\frac{2\pi \sin\theta_x}{\lambda}x + \frac{2\pi \cos\theta_x}{\lambda}z)}$ , can be calculated using the Born and

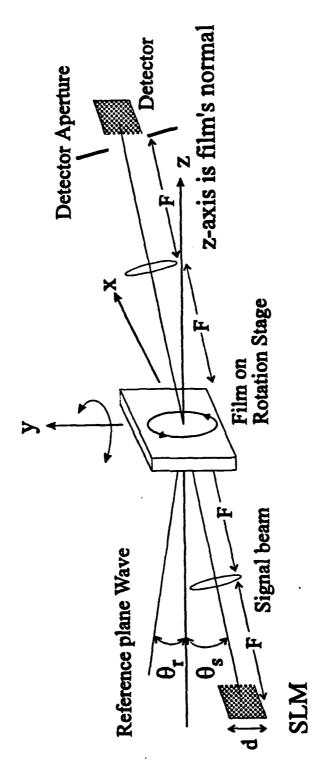


Figure 1: Setup for peristrophic multiplexing.

paraxial approximations and integrating over the volume of the hologram. Assuming that the tranverse (x, y) dimensions of the film are much larger than the bandwidth of the images, the Bragg selectivity can be shown to be

$$d\theta = \sqrt{\frac{2\lambda}{t} \left( \frac{\cos \theta_s}{\sin \theta_r (\sin \theta_s + \sin \theta_r)} \right)} , \qquad (5)$$

where t is the thickness of the material. Using  $\lambda=488 \,\mathrm{nm}$ ,  $t=38 \mu\mathrm{m}$ , and  $\theta_s=\theta_r=30^\circ$  results in a selectivity of about 12°. The Bragg matching requirement is the dominant effect if  $\frac{d}{F}>\sqrt{2\lambda\cos\theta_s(\sin\theta_s+\sin\theta_r)/t\sin\theta_r}$ . For most material thicknesses, the Bragg matching criterion determines the required rotation for peristrophic multiplexing. In our experiments, because the thickness of the film is only  $38 \mu\mathrm{m}$ , the image could be filtered out before the gratings become non-Bragg matched.

#### 3.0 Experimental Results

The experimental setup is the same as in Fig. 1 except a rotation stage was added to rotate the film around a vertical axis as well as around the film's normal. This makes it possible to combine peristrophic and angle multiplexing. The film was located a significant distance from the Fourier plane so that the signal beam was approximately uniform. For each peristrophic position, multiple holograms are stored using standard angle multiplexing by rotating the medium. A spatial light modulator (SLM) was used to present images (cartoons) to the system. Each frame is numbered according to the sequence in which they were stored. The reference and signal beams were initially incident at  $\pm 30^{\circ}$  from the film's normal. The reference beam intensity was 1.1 mW/cm<sup>2</sup> and the signal beam had 300  $\mu$ W in about a 1 cm by 0.5 cm area. The film was rotated in-plane by 3° between each set of angle multiplexed holograms to enable the other holograms to be filtered out. Eq. 3 predicts a required rotation of about 9° for Fourier plane hologram while Eq. 4 predicts about 1.7° rotation for image plane. The 3° was experimentally obseved

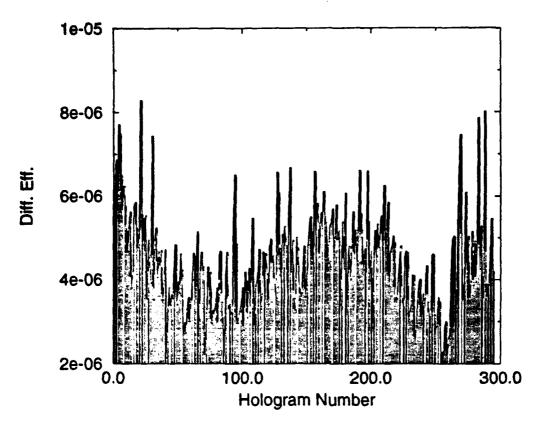


Figure 2: Diffraction efficiency vs hologram number for 295 holograms stored in 38  $\mu m$  thick film.

for the in-between (Fresnel) case we used. Each angle multiplexed hologram was also separated by 3°. The initial exposure time was 0.11 seconds, but starting at hologram number 26, each hologram was exposed for 0.005 seconds longer than the previous hologram to correct for the lost sensitivity due to run time [2]. There was a 1.5 second delay between holograms to allow the rotation stages to completely stop. 295 holograms were stored in the polymer by peristrophic multiplexing 59 times and storing 5 angle multiplexed holograms with each peristrophic position. The diffraction efficiency of the 295 holograms is plotted in Fig. 2. The average efficiency was  $\sim 4 \times 10^{-6}$  and the variations are primarily due to variation in the average intensity of the frames. In separate experiment, we stored equal amplitude plane wave holograms and observed a decrease in diffraction efficiency proportional to  $1/M^2$  [7].

Previously we stored M = 10 holograms with roughly  $10^{-3}$  diffraction efficiency [2] limited by the angular bandwidth of the optical system. Peristrophic multiplexing made it possible to store M = 295 holograms at the same location with a diffraction efficiency of  $\sim 4 \times 10^{-6}$ . Thus, peristrophic multiplexing allowed for almost two orders of magnitude increase in the storage capacity of the DuPont photopolymer and changed the limiting factor from the angular bandwidth of the optical system to the dynamic range of the material.

#### 4.0 Architecture

Figure 3 shows the implementation of a 3-D holographic disk that uses spatial, angle and peristrophic multiplexing. The information to be recorded is presented by a spatial light modulator (SLM) which modulates the signal beam. The reference beam then interferes with the signal beam and the information is recorded throughout the volume of storage medium where the two beams overlap. The surface density can be increased by using angle multiplexing (changing the angle between the reference beam and the signal beam) to record more holograms in the same volume. To further increase the storage density, the reference beam is also rotated about the signal beam to implement peristrophic multiplexing. This rotation of the reference beam either shifts the reconstructed images from the previously recorded holograms off the detector or the stored holograms becomes Bragg mis-matched, allowing for more holograms to be recorded. The storage capacity of the system is increased by rotating the storage medium to record at non-overlapping regions on the disk (spatial multiplexing). Figure 4 shows the theoretical surface density and the number of holograms that can be multiplexed at a given location on the disk as a function of the storage medium's thickness using the implementation shown in Figure 3. The geometry limited density was calculated using the parameters shown in Figure 4. The density is approximately 10 bits per micron squared for a medium

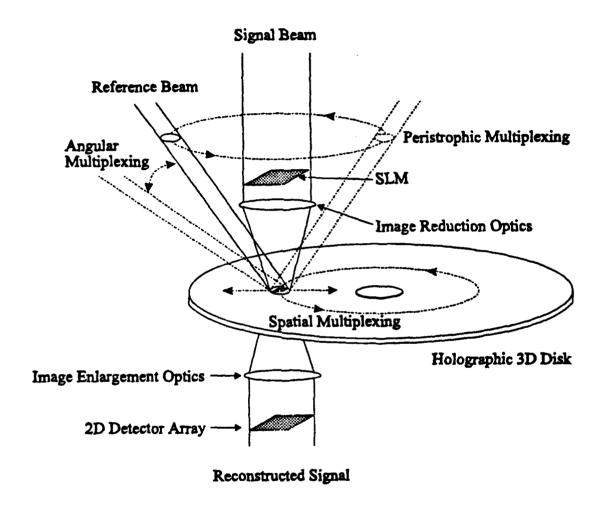


Figure 3: 3-D holographic disk system using both angle and peristrophic multiplexing.

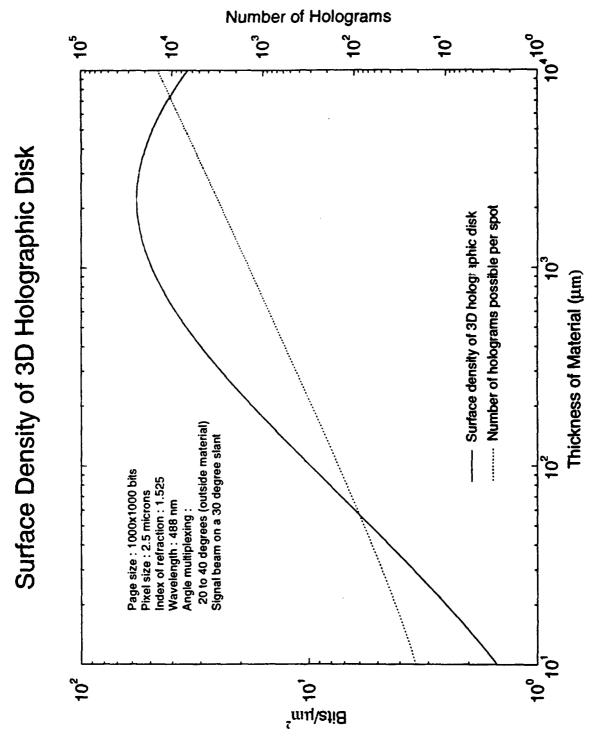


Figure 4: Storage density and required number of holograms per location vs film thickness for a 3-D disk that utilizes both peristrophic and angle multiplexing.

thickness of only 0.1mm. This density is achieved by storing roughly 150 holograms with a page size of 10<sup>3</sup>x10<sup>3</sup> bits. The density does not grow continuously as a function of increasing thickness even though the number of multiplexed hologram increases. This is due to the fact that light defocuses and requires more area as the material gets thicker. The storage medium for the 3-D holographic disk can be any holographic material such as photorefractives and photopolymers. Photorefractives are re-programmable, optically erasable and can be made to large thickness with good optical quality. Recently, 10,000 holograms were recorded at one location in LiNbO3 [8] and could be reconstructed with high fidelity. Photopolymers on the other hand are inexpensive, easy to use and offer non-volatile storage. We have previously recorded 300 holograms - 3 at each location, 100 spatial locations on a ring around a photopolymer disk. Thus we have demonstrated all the aspects of the 3-D holographic disk system. Currently we are working on demonstrating storage densities close to the theoretically predicted limits.

## References

- W. K. Smothers, T. J. Trout, A. M. Weber, and D. J. Mickish, 2<sup>nd</sup> Int. Conf. on Holographic Systems, Bath, UK (1989).
- 2. K. Curtis and D. Psaltis, Appl. Opt., 31,7425 (1992).
- 3. K. Curtis and D. Psaltis, in OSA Annual Meeting, 23 of 1992 OSA Technical Digest Series (OSA, Washington D.C., 1992).
- 4. D. Psaltis, D. Brady, X. G. Gu, S. Liu, Nature, 343, 325 (1990).
- 5. F. H. Mok, Opt. Lett., 18,915 (1993).
- H. Y. S. Li, Ph.D. dissertation Photorefractive 3-D Disks for Optical Data Storage and Artificial Neural Networks (California Institute of Technology, Pasadena, Ca., 1994).
- 7. D. Brady and D. Psaltis, J.O.S.A. A. 9,1167 (1992).
- G. Burr, F. Mok. D. Psaltis. OSA Annual Meeting, October 1993, Toronto, Paper Tu-H6.